

CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

**FAULT EVALUATION REPORT FER-234
SURFACE FAULT RUPTURE ALONG THE JOHNSON VALLEY,
HOMESTEAD VALLEY, AND RELATED FAULTS
ASSOCIATED WITH THE
M_s 7.5 28 JUNE 1992 LANDERS EARTHQUAKE**

by
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November 17, 1992

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INTRODUCTION

Traces of the Johnson Valley, Homestead Valley, and related faults (Figure 1) are evaluated in this Fault Evaluation Report (FER) as a result of surface fault rupture associated with the 28 June 1992 M_s 7.5 Landers earthquake. Traces of the Johnson Valley and Homestead Valley faults in the Landers-Yucca Valley study area were zoned for special studies in March 1988 on the Landers and Yucca Valley North 7.5-minute quadrangles (CDMG, 1988a, 1988b) (Figures 2a, 2b) as part of DMG's statewide 10-region (Mojave Desert Region) Fault Evaluation and Zoning Project as authorized by the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1992; Hart and others, 1988). Extensive surface fault rupture associated with the Landers earthquake occurred within SSZ boundaries, but was also located outside SSZ boundaries on both the Johnson Valley and Homestead Valley faults. In addition, rupture occurred along previously unmapped faults, transferring slip from the Johnson Valley to the Homestead Valley faults. Surface fault rupture associated with the Landers earthquake requires revisions to the 1988 SSZ Maps of the Landers and Yucca Valley North quadrangles. Minor triggered slip along traces of the Pinto Mountain fault also require minor zoning revisions in the Yucca Valley South quadrangle (CDMG, 1988c).

SUMMARY OF AVAILABLE DATA

No references for the Johnson Valley and Homestead Valley faults in the FER study area have been published since the 1988 SSZ Maps of the Landers and Yucca Valley North quadrangles were issued. The reader is referred to Bryant (1986) and Manson (1986) for complete review and evaluation of mapping of the Johnson Valley and Homestead Valley faults and zoning rationale. This FER largely will be limited to the evaluation of fault rupture that occurred in the Landers and Yucca Valley North 7.5-minute quadrangles. In addition, interpretation of BLM (1978) and USDA (1953) aerial photographs by this writer was done along selected traces of the Johnson Valley, Homestead Valley, and Kickapoo faults.

JOHNSON VALLEY FAULT

Traces of the Johnson Valley fault zoned for special studies in the Yucca Valley North quadrangle (Figure 2a) were based on mapping by Bryant (1986) (referred to as Fault I by Bryant). An eroded west-facing scarp in older alluvium, locally ponded alluvium, a linear trough in older alluvium, and linear tonal contrasts in Holocene alluvium, based on interpretation of 1978 BLM air photos by Bryant (1986), were the basis for zoning Fault I. Minor surface fault rupture associated with the March 1979 Homestead

Valley earthquake swarm north of the Yucca Valley North quadrangle suggested a potential for rupture along this fault (see Manson, 1986 and Hill and others, 1980a). Bryant (1986) stated that geomorphic evidence for Holocene offset along the southern Johnson Valley fault was marginal, but the association with the southern extent of the aftershock zone from the 1979 Homestead Valley earthquake was viewed as justification for zoning.

Traces of the Johnson Valley fault zoned for special studies in the Landers quadrangle (Figure 2b) were based on mapping by Manson (1986). Traces of the Johnson Valley fault were interpreted by Manson using 1:30,000 USBLM (1978) aerial photographs along with limited field reconnaissance mapping. This mapping was augmented with fault rupture mapping by Hill and others (1980b) that occurred following the 1979 Homestead Valley earthquake. For a further discussion of previous mapping of the Johnson Valley fault, refer to Manson (1986).

A 3.4 km long gap in zoning existed on the 1988 SSZ Maps of the Yucca Valley North and Landers quadrangles (Figures 2a,2b). This was based mainly on the lack of geomorphic features indicative of latest Pleistocene to Holocene faulting associated with the Johnson Valley fault. The 1992 surface rupture closed this gap. An area critical to the decision made not to connect the two fault strands is located along the northern margin or levee of the east-west drainage channel just north of Flamingo Heights (locality 1, Figure 2b). There is no lateral deflection of this channel margin, although the southern margin arguably is deflected. Significantly, this location which ruptured in 1992 involves a change to a more southerly trend along the Johnson Valley fault. A linear projection to the southeast encounters a right-lateral deflection of this wash near the southern part of section 14 (locality 2, Figure 2b). No obvious geomorphic features or linear tonal contrasts are associated with this drainage deflection and no rupture associated with the 1992 Landers earthquake was observed.

HOMESTEAD VALLEY FAULT

The southern Homestead Valley fault in the Landers quadrangle was zoned for Special Studies in 1988, based on the mapping of Hill and others (1980a, 1980b) and Manson (1986) (Figure 2b). Manson stated that the Homestead Valley fault is an active, northwest-trending right-lateral strike-slip fault that extends from near the Emerson fault (north of this FER study area) southeastward to Homestead Valley. A maximum right-lateral strike-slip offset of 10 cm along the Homestead Valley fault was associated with the 1979 Homestead Valley earthquake.

LANDERS EARTHQUAKE

A magnitude M_s 7.5 earthquake occurred at 04:57 local time on 28 June 1992 (Toppozada and Wilson, 1992). The epicenter was located near the hamlet of Landers, about 8 km north of Yucca Valley (Figure 5). Surface fault rupture associated with the M_s 7.5 Landers earthquake occurred along the Johnson Valley, Homestead Valley, Emerson, and Camp Rock faults (Figure 5). Rupture south of the Pinto Mountain fault occurred along previously unmapped faults now named the Eureka Peak and Burnt Mountain faults (see Treiman, 1992a and 1992b for evaluations of the Eureka Peak and Burnt Mountain faults in the Yucca Valley South and Joshua Tree South 7.5-minute quadrangles).

Rupture extended for approximately 85 km along a north to northwest trend from south of the town of Yucca Valley to about 32 km southeast of Barstow. Fault rupture was characterized by predominantly

right-lateral strike-slip displacement along previously mapped faults, although significant fault rupture occurred along several unmapped faults. Right-lateral strike-slip displacement averaged about 200 to 300 centimeters (cm) and reached a maximum of about 550 cm along the Emerson fault. Vertical displacements often were associated with the strike-slip displacement and ranged from an average of 30 cm (both west and east sides down) to a maximum of about 200 cm (west side down) along the Emerson fault.

Approximately 3 weeks were spent in the Yucca Valley area by this writer in order to map surface rupture associated with the Landers earthquake. Field mapping by this writer and many other geologists from DMG and the U.S. Geological Survey was accomplished principally by mapping directly onto 1:6,000 scale aerial photographs taken 2 and 5 days after the earthquake (Curtis, 1992). However, many traces were mapped during the first week by plotting directly onto 1:24,000 scale topographic maps.

The majority of field mapping by this writer was concentrated north of the FER study area along traces of the Homestead Valley, Emerson, and related faults. Thus, the majority of field mapping in the Landers and Yucca Valley North quadrangles was accomplished by DMG and USGS geologists (including M. Clark, R. Greenwood, E. Hart, C. Higgins, J. Kahle, J. Lienkaemper, J. MacMillan, J. Matti, T. Powers, M. Rymer, R. Sharp, J. Treiman, and C. Wills). About 1½ days were spent mapping in the Flamingo Heights area and 1 day checking traces of the Pinto Mountain fault (eastward to Twentynine Palms). Approximately 1 week was spent interpreting the 1:6,000 scale aerial photographs covering the FER study area. This was accomplished using stereoscopic interpretation augmented with interpretation using a binocular microscope (11x magnification) in order to identify and accurately portray the location and pattern of surface fault rupture. This mapping was then compared to and augmented with field mapping of geologists from DMG and USGS and plotted using a Bausch and Lomb Zoom Transfer scope onto the Yucca Valley North and Landers 7.5-minute topographic maps (Figures 3a and 3b). Two days were spent in the Yucca Valley area in early November 1992 by J. Treiman and this writer in order to field check data received in October 1992. Slip data shown on Figures 3a and 3b were compiled from field mapping by DMG and USGS geologists.

Johnson Valley Fault Rupture

Surface rupture along the Johnson Valley fault associated with the Landers earthquake generally occurred along mapped traces of the fault in the Landers quadrangle, although several complex zones involved in the step-over to the Homestead Valley fault continued outside the SSZ boundaries (Figures 2b, 3b). The correlation between previously mapped and zoned traces of the Johnson Valley fault and the 1992 ruptures was not as good in the Yucca Valley North quadrangle, mostly due to the moderately to poorly defined nature of the southern Johnson Valley fault and the complexities involved at the southern (distal) end of fault rupture (Figures 2a, 3a).

Surface fault rupture associated with the Landers earthquake along the Johnson Valley fault is very complex in detail, due to the nature of fault rupture in thick, generally unconsolidated granular alluvium. Surface fault rupture was expressed in zones that varied from a few meters to 100 meters wide or more. Ruptures often consisted of multiple strands, generally delineated by left-stepping en echelon fractures and fissures, scarps, moletracks, locally anastomosing or branching fractures, local graben, minor pressure ridges and thrust faults (e.g. Photos 1 and 2). Maximum right-lateral strike-slip displacement of 310 cm was observed just west of Acoma Road (½ km south of locality 3, Figure 3b). Vertical

displacement was generally down to the west and reached a maximum of 40 cm at locality 4 (Figure 3a) and locality 5 (Figure 3b).

Homestead Valley Fault Rupture

Surface fault rupture along the Homestead Valley fault associated with the Landers earthquake was characterized by up to 160 cm of right-lateral strike-slip displacement in the Landers quadrangle (locality 6, Figure 3b), although this displacement increased to greater than 300 cm to the north in the Emerson Lake 7.5-minute quadrangle. A vertical component of offset occurred along this fault, generally down to the west, and reached a maximum of about 30 cm (locality 7, Figure 3b). The 1992 ruptures generally coincided with the 1979 ruptures, although several smaller ruptures occurred to the west of the principal trace (Figures 2b, 3b).

A complex step in the Homestead Valley fault occurs at the northern edge of the Landers quadrangle (Figures 2b, 3b). Rupture was difficult to follow to the edge of the quadrangle, probably being distributed across a bedrock high and as thrusting along the eastern side of this hill. The nature of rupture along the east side of the bedrock hill was not clear and has been interpreted as having formed either by thrust faulting or by landsliding. Additional field work in order to resolve these differences is planned by the USGS. Traces of these ruptures extend south into the Landers quadrangle, however, and will be considered as tectonic.

Pipes Wash Area

A fault was postulated by Hawkins and McNey (1979) along the east side of Pipes Wash just west of Spy Mountain, based on cracks that formed during the 1979 Homestead Valley earthquake and the linearity of the wash. However, Manson (1986) found no evidence of faulting in Pleistocene alluvium that forms the channel wall at locality 20 (Figure 3b). In addition, Manson concluded that the linear margin of Pipes Wash was not unique to this location and did not necessarily indicate recent faulting. The 1979 fractures along the slope of Pipes Wash were thought to be incipient slumping related to shaking rather than surface fault rupture, although a tectonic origin could not be ruled out (Hill and others, 1980a).

Many cracks were observed by K. Umbarger (p.c. 1992) in and along the east side of Pipes Wash in the general vicinity of the 1979 fractures (Umbarger stated that the floor of Pipes Wash was "criss-crossed" with fractures) (Figure 3b). Although most of the cracks appear to have been formed from shaking or slumping, some of the cracks formed along the base of the west-facing slope of Pipes Wash. The sense of displacement of these ruptures was predominantly vertical, west side down. Near locality 20 the sense of vertical displacement may have been reverse (p.c., F. Jordan, October 1992). A component of both right and left-lateral slip was reported by Umbarger along a northwest trend. Magnitude of displacement was 4 to 5 cm vertical and from 2 to 15 cm of lateral (both left and right). Umbarger stated that left-lateral slip was observed along the same trend as the observed right-slip. The trend of the ruptures was somewhat curvilinear, but specific areas involving either right or left-lateral slip could not be related to the trend of the ruptures. J. Treiman (p.c. 11-92) observed photos of these ruptures and stated that there did not seem to be any systematic pattern of cracking.

The Pipes Wash area was field checked by this writer and J. Treiman on November 10, 1992. Prominent cracks located near the crest of the west-facing slope along the east side of Pipes Wash were extensional and clearly related to slumping. Cracks mapped by Umbarger near the base of the slope (in very soft sand) were completely obliterated at the time of the field inspection. A sinuous west-facing scarplet extended for about 210 meters north of University Road (locality 20, Figure 3b). The 5 cm high scarplet, which was identified as a reverse or thrust fault by F. Jordan, is located at or within about 1 meter of the toe of the slope and is in loose, fine to medium grained sand. Several hand-dug pits were excavated across this scarplet. No fault planes were associated with this scarplet, which in loose granular alluvium is not surprising. A feature common in all of the excavations was the overriding of the "upper plate" over the "lower plate" (indicated by a dry grass mat separating the upper and lower plates). A distinctive silt horizon observed in one excavation was not displaced.

A probable explanation for this sinuous scarplet is as follows. A debris flow (sand flow) occurred in the past prior to the Landers earthquake, as indicated by a thin organic mat underlying the upper silty sand unit (Figure 6). This organic layer represented the talus surface prior to the sand flow. Shaking from the Landers earthquake caused the material in the talus to flow to the west an additional 10 to 20 cm, overriding dry grass growing on the now buried surface. This explanation is thought to be consistent with the observations because: (1) no displacement of a distinctive slit layer was observed in one excavation, and (2) the 10 to 20 cm length that the "upper plate" overrode the "lower plate" seems inconsistent with a thrust fault in such cohesionless material.

Kickapoo Fault Rupture

Right-lateral strike-slip displacement was transferred from the Johnson Valley fault to the Homestead Valley fault along the Kickapoo fault (Figure 3b). The Kickapoo fault, so named because it crosses and offsets Kickapoo Road (labelled Ernestine Road on Figure 3b) is a previously unmapped north to north-northeast trending right-lateral strike-slip fault zone (this fault zone has also been referred to as the Landers fault by California Institute of Technology). A component of down to the east vertical offset (maximum of 106 cm; Photo 3) accompanied right-lateral strike-slip displacement of 290 cm (maximum) (localities 8 and 9, Figure 3b). Rupture is expressed as left-stepping en echelon breaks in individual zones to about 80 meters wide.

Two principal rupture zones formed in the 1992 event, the western zone of rupture having the most amount of displacement. The eastern zone of ruptures had a maximum reported right-lateral offset of 29 cm (Figure 3b).

Although previously unmapped, the central part of the Kickapoo fault is weakly and discontinuously expressed by linear tonal contrasts in alluvium, eroded scarps and truncated Pleistocene alluvium (localities 10-13, Figure 2b). These features are moderately defined at best and do not entirely coincide with the 1992 rupture, but with the benefit of hindsight they do indicate that the Kickapoo fault has previously ruptured.

Several northeast trending fractures splayed off east of the southern Kickapoo fault and are characterized by both right and left-lateral strike-slip offset, generally on the order of less than 10 cm, although one strand had 20 cm of right-lateral slip and 10 cm of vertical (down-to-the east) (locality 14,

Figures 2b, 3b). These minor faults lack geomorphic expression of recent offset in latest Pleistocene to Holocene alluvium.

Fault Zone A

Fault rupture occurred west of the Johnson Valley fault in the Flamingo Heights area along several northeast trending faults (Figures 3a,3b; Photos 4 and 5). This complex zone of generally right-lateral strike-slip faults was not previously recognized. Magnitude of offset reached a maximum right-lateral displacement of 60 cm with a vertical component of 20 cm (down-to-the east) (locality 15, Figure 3a). Several faults also displayed left-lateral strike-slip displacement up to about 5 cm. Many ruptures were characterized primarily by extension and vertical displacement.

There is no geomorphic expression of this northeast-trending zone of ruptures in latest Pleistocene alluvium, based on interpretation of 1953 USDA, 1978 BLM and 1992 Curtis air photos.

Pinto Mountain Fault

Triggered slip occurred along strands of the Pinto Mountain fault, a left-lateral strike-slip fault, as indicated in the Yucca Valley North and South quadrangles (Figure 3a). Maximum vertical displacement of 6 cm (down-to-southeast) was observed at locality 16 (Figure 3a). A lateral component of offset at this location is somewhat ambiguous. The fracture pattern both northeast and southwest of this location is crudely right-stepping, suggesting a left-lateral component of displacement compatible with known displacement on the Pinto Mountain fault. However, a right-lateral component of about 1 cm was measured across an unpaved road, based on matching points within an extensional crack. This maximum offset is on a south-facing slope and it is suspected that migration toward the free-face can explain the anomalous right-lateral component. Also, the 6 cm of vertical offset has no doubt been enhance by slumping and shaking.

Additional minor cracking was located in a zone about 45 meters wide east of Highway 247 (locality 17, Figure 3a). Cracking here is mostly extensional, but both right-stepping cracks along a N63°E trend and left-stepping cracks along a N05°E zone were observed. However, both left and right-lateral components of offset were observed along the NE trending fractures to about 1 cm. Most of the fractures were extensional to about 1.5 cm. The lack of systematic offset suggests that these cracks may be related to shaking. However, they do plot on the Pinto Mountain fault, so triggered slip cannot be ruled out.

Additional cracks to the east of locality 17 (Figure 3a) are extensional and are probably related to slumping or migration of the free face of the wash on the north side of Yucca Valley airport.

SEISMICITY

Seismicity in the Landers study area for the period 1932 to 1985 is dominated by the 1979 Homestead Valley earthquake swarm (Figure 4). Hutton and others (1980) stated that only one event of magnitude 2.5 to 3.0 occurred in Homestead Valley during the period between 1 January 1970 and 14 March 1979. More than 3,000 events occurred in this region between 15 March and 30 June 1979.

Earthquake epicenters in the FER study area for the period April to July 1992 are shown in Figure 5 (Hauksson and others, 1992). The Joshua Tree earthquake sequence of April 1992 is located south of the Pinto Mountain fault.

CONCLUSIONS

The 28 June 1992 M_s Landers earthquake produced significant surface fault rupture along previously zoned traces of the Johnson Valley and Homestead Valley faults (Figures 2a, 2b, 3a, and 3b). In addition, significant fault rupture occurred along previously unmapped faults west of Flamingo Heights (Fault Zone A in this report) and along a north-trending step-over between the Johnson Valley and Homestead Valley faults (Kickapoo fault) (Figures 3a and 3b).

JOHNSON VALLEY AND HOMESTEAD VALLEY FAULTS

Maximum right-lateral strike-slip displacement along the Johnson Valley fault was 310 cm. The Homestead Valley fault produced 160 cm of right-slip in the Landers quadrangle (Figure 3b), but maximum right-lateral offset of greater than 300 cm was observed north of the FER study area in the Emerson Lake 7.5-minute quadrangle. A 3.4 km long segment of the southern Johnson Valley fault was not zoned for special studies in the southern Landers and northern Yucca Valley North quadrangles (Figures 2a and 2b), based on a lack of youthful geomorphic features. However, fault rupture associated with the Landers earthquake demonstrated that a connection does exist. Geomorphic expression of this connection is generally poorly defined. Fault ruptures along both the Johnson Valley and Homestead Valley faults extended beyond the delineated special studies zones in the Yucca Valley North and Landers quadrangles (Figures 2a, 2b), necessitating zoning revisions.

Cracks formed during the 1992 Landers earthquake at the base of the west-facing slope along the east side of Pipes Wash, based on mapping by K. Umbarger (p.c., October 1992) (locality 20, Figure 3b). The sense of vertical displacement was down-to-the-west (4 to 5cm) with components of both right and left-lateral slip (2 to 15cm). Evidence of systematic right-lateral or left-lateral offset were not observed.

The vertical component of offset in the vicinity of University Road (locality 20, Figure 3b) was interpreted to be reverse by F. Jordan (p.c., November 1992). A sinuous scarplet at the base of the eastern slope of Pipes Wash observed by this writer November 10, 1992 is best explained as a minor debris or sand flow in response to shaking, rather than surface fault rupture (Figure 6). It is probable that fractures mapped by Umbarger at the base of the eastern slope of Pipes Wash formed in response to settlement of unconsolidated granular alluvium in Pipes Wash.

KICKAPOO FAULT

Right-lateral strike-slip displacement was transferred from the Johnson Valley fault to the Homestead Valley fault along the previously unmapped north-trending Kickapoo fault (Figure 3b). Maximum right-lateral strike-slip offset of 290 cm, with a significant down-to-the-east component of vertical displacement (106 cm), was observed along this complex fault zone (Figure 3b). Moderately defined geomorphic features including an east-facing scarp in Pleistocene alluvium and linear tonal contrasts generally indicate the location of traces of the Kickapoo fault (Figure 2b). These features are relatively subtle and, similar to the geomorphic expression of the southern Johnson Valley fault, suggest that there is a relatively long return period for significant surface fault rupture events.

FAULT ZONE A

A broad, northeast-trending zone of generally right-lateral strike-slip displacement with significant down-to-the-southeast vertical offset (max. 60 cm right lateral; 20 cm vertical) ruptured west of the Flamingo Heights area (Figures 3a and 3b). This northeast-trending zone (referred to in this FER as Fault Zone A) previously was unmapped. There is no geomorphic expression of this fault in a gently eastward sloping older alluvial fan surface of probable late Pleistocene age, based on interpretation of 1978 BLM and 1992 Curtis aerial photographs by this writer.

PINTO MOUNTAIN FAULT

Triggered slip occurred along previously zoned traces of the east-trending, left-lateral strike-slip Pinto Mountain fault in the Yucca Valley North and Yucca Valley South quadrangles (Figures 2a and 3a). Maximum vertical displacement was 6 cm (down-to-the-southeast) at locality 16 (Figure 3a). A component of right-lateral strike-slip displacement was measured (about 1 cm), but crudely right-stepping en echelon cracks suggest a component of left-lateral slip. The location of this offset along a relatively steep slope and the ambiguous component of strike-slip displacement indicates that shaking and migration toward the slope's free face have significantly modified the observed surface displacements.

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1992).

JOHNSON VALLEY AND HOMESTEAD VALLEY FAULTS

Revise the 1988 SSZ Maps of the Yucca Valley North and Landers quadrangles to incorporate all surface fault ruptures associated with the 1992 Landers earthquake characterized by greater than 1 cm of lateral or vertical displacement and having continuity along a linear trend as depicted in Figures 2a and 2b. Principal references cited should be Hill and others (1980a, 1980b), Bryant (1986), Manson (1986), and Bryant, this report.

KICKAPOO FAULT

Zone for special studies traces of the Kickapoo fault that ruptured in the 1992 Landers earthquake as indicated in Figure 2b. Because the Kickapoo fault consists of a broad and complex zone of fault rupture, fault rupture recommended for zoning have the following two criteria: (1) displacement is greater than 1 cm, and (2) the ruptures must have continuity along a linear trend that indicates fault rupture rather than fracturing caused by shaking or lateral spreading. Principal reference cited should be Bryant, this report.

FAULT ZONE A

Zone for special studies traces of Fault Zone A that ruptured in the 1992 Landers earthquake as indicated in Figures 2a and 2b. Because Fault Zone A consists of a broad and complex zone of fault rupture, fault rupture recommended for zoning have the following two criteria: (1) displacement is greater than 1 cm, and (2) the ruptures must have continuity along a linear trend that indicates fault rupture rather than fracturing caused by shaking or lateral spreading. Principal reference cited should be Bryant, this report.

PINTO MOUNTAIN FAULT

Minor triggered slip associated with the 1992 Landers earthquake was observed along traces of the Pinto Mountain fault. Revise the Yucca Valley North and Yucca Valley South quadrangles to incorporate the 1992 triggered slip as indicated on Figure 2a.

*Reviewed & approved.
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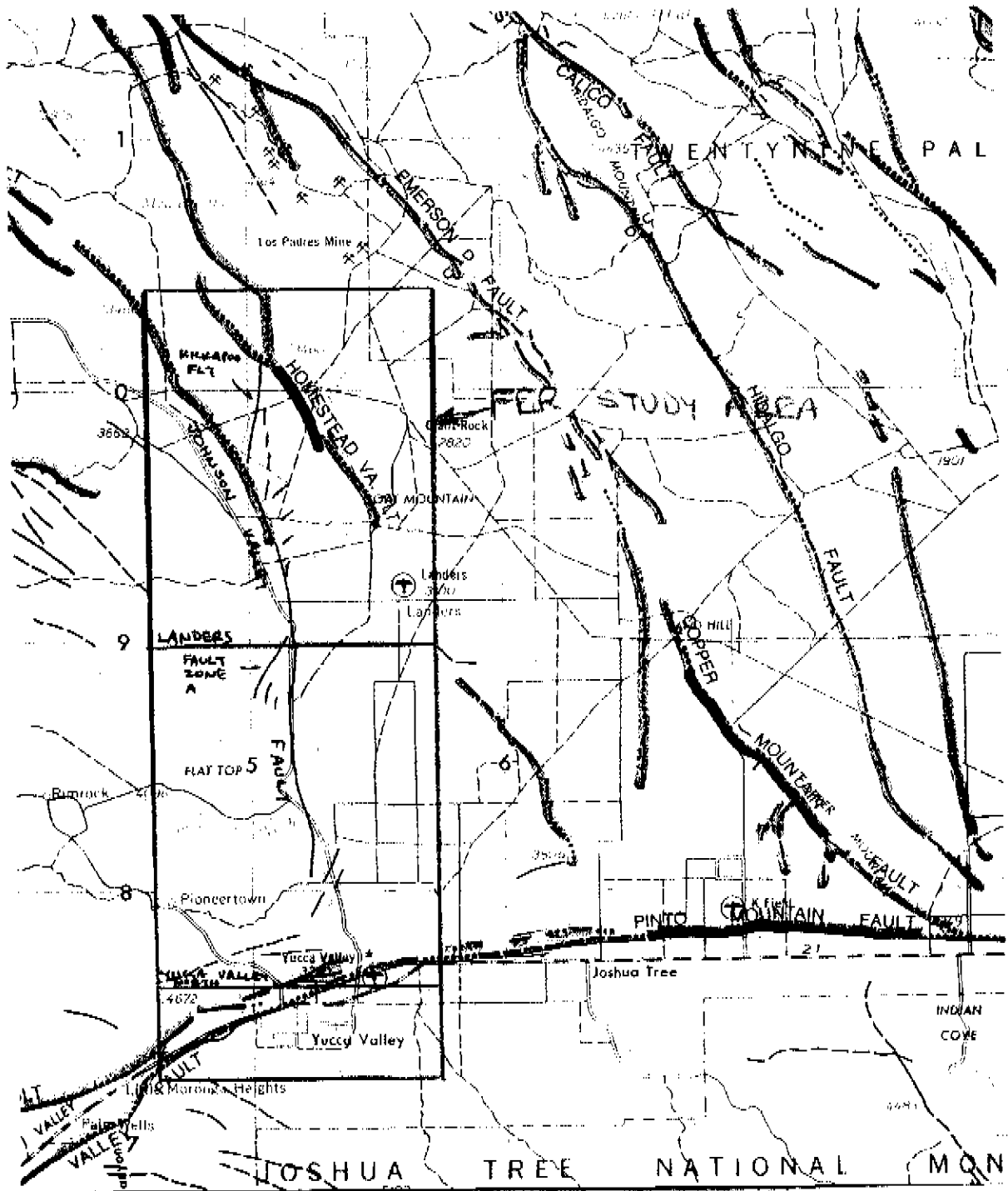


Figure 1 (to FER-234). Location of faults in the Landers-Yucca Valley study area. Fault rupture associated with the 28 June 1992 Landers earthquake are highlighted in red. Base map from Bortugno and Spittler (1986), scale 1:250,000.

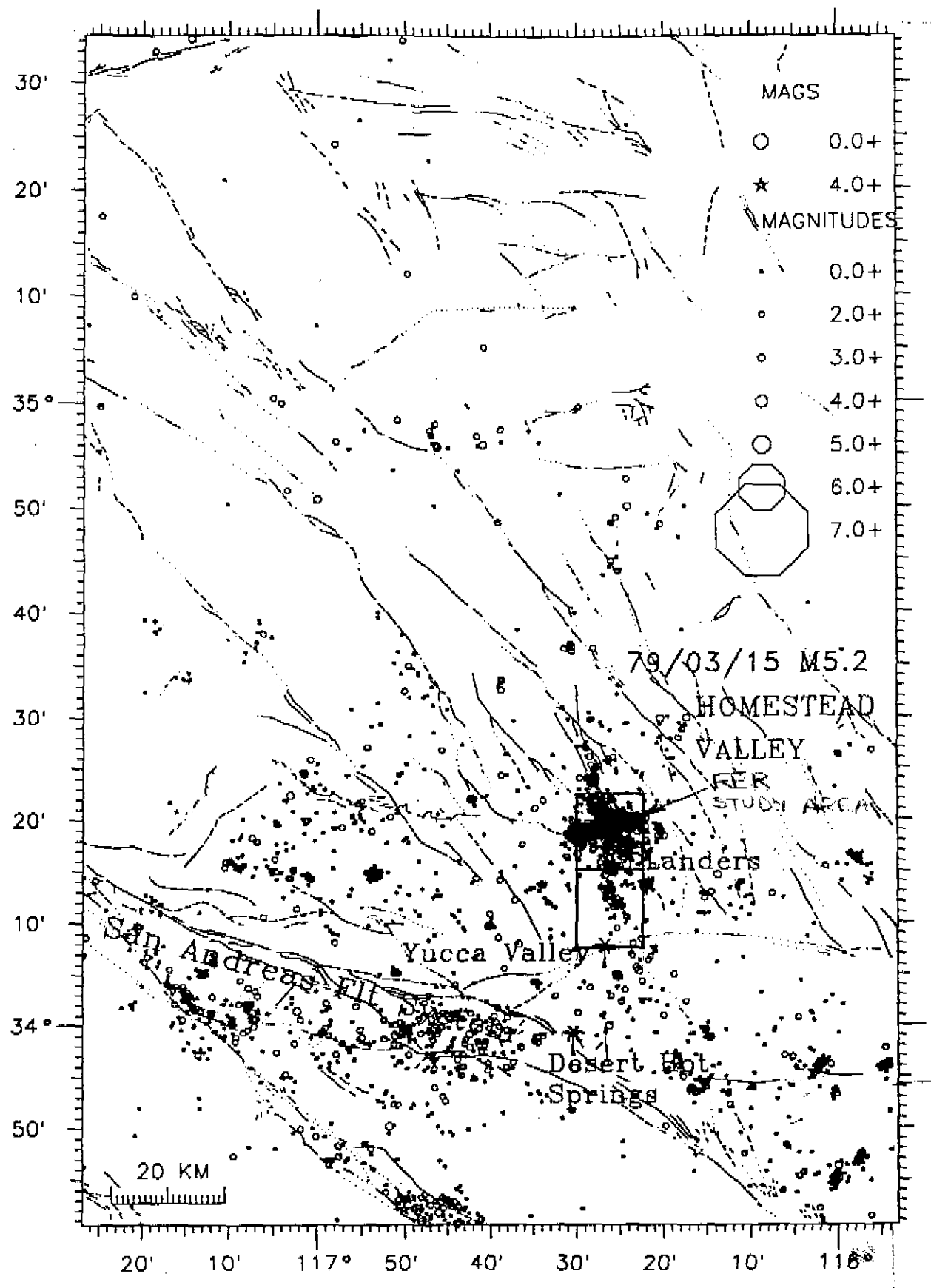


Figure 4 (to FER-234). Seismicity in the Landers-Yucca Valley study area for the period 1979 to 1980, based on locations from Hauksson and others, 1992.

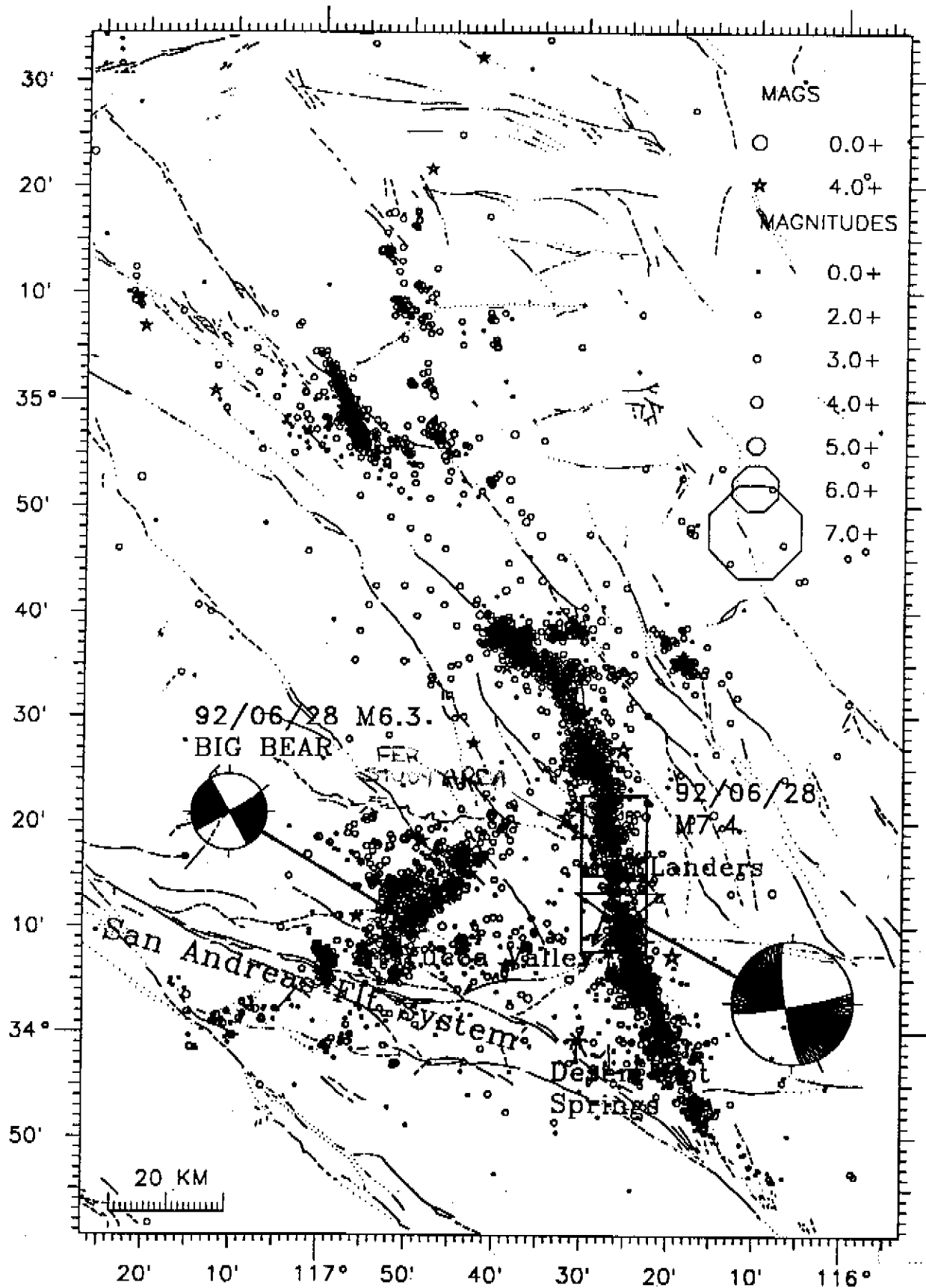
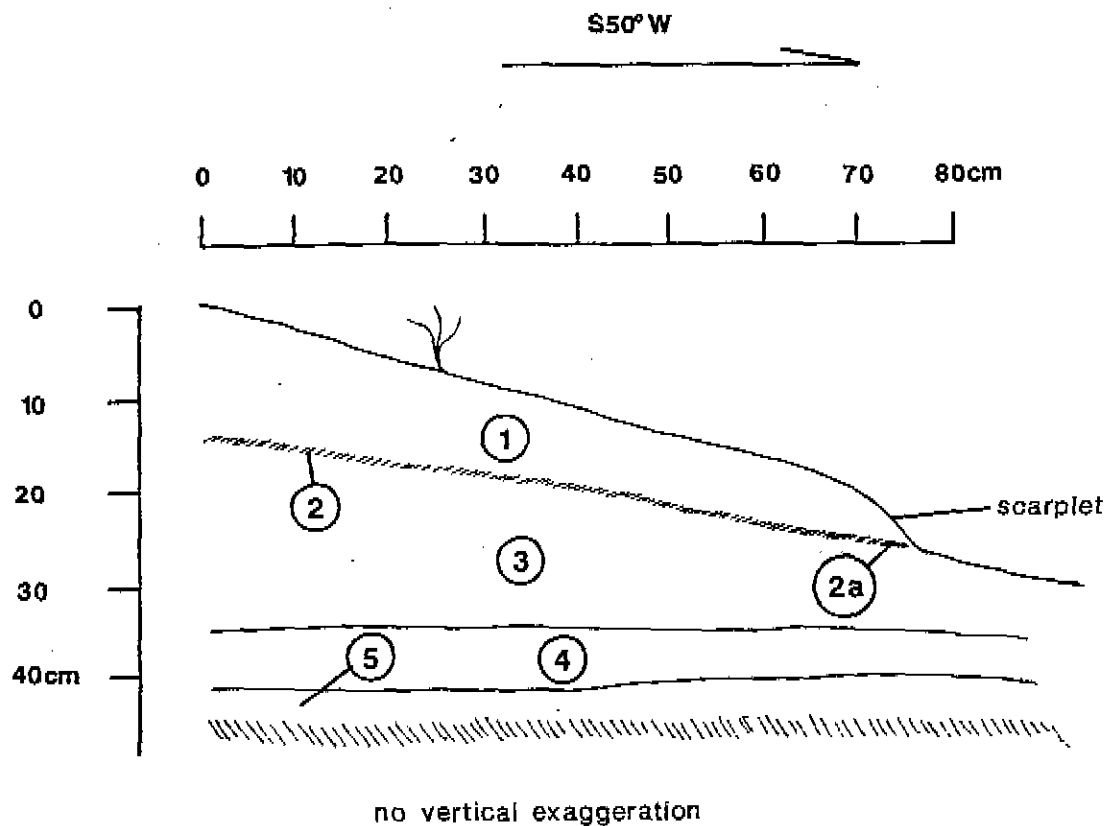


Figure 5 (to FER-234). Seismicity in the Landers-Yucca Valley study area for the period June 28 to August 18, 1992. Map from Hauksson and others, 1992.



DESCRIPTION OF UNITS

- ① Grey silty sand; fine to medium grained; cohesionless.
- ② Thin (2-5mm) organic rich horizon - former grass-covered slope?
- ②a Unit 1 sand overlies dried grass of pre-Landers earthquake surface.
- ③ Grey medium to coarse-grained sand.
- ④ Grey silt; slightly friable; unit not displaced.
- ⑤ Medium to coarse-grained sand.

Figure 6 (to FER-234). Sketch of hand-dug excavation across a sinuous west-facing scarplet formed during the 1992 Landers earthquake (107 meters northwest of locality 20, Figure 3b). Sketch by Bryant (this report)



Photo 1 (to FER-234). Aerial view of the Johnson Valley fault at locality 5 (Figure 3b). Fault has offset the chalk parking stripes 230 ± 10 cm right-laterally across a zone about 10 meters wide. A down-to-the-west vertical component of 40 cm was measured.



Photo 2 (to FER-234). A well-defined west-facing scarp in late Pleistocene alluvium delineates surface fault rupture along the Johnson Valley fault in the Flamingo Heights area (locality 18, Figure 3a).



Photo 3 (to FER-234). The previously unmapped "Kickapoo" fault was characterized by approximately 70 cm right-lateral and up to 106 cm of vertical (down to the east) displacement at this location (just north of locality 8, Figure 3b). A left-step in the fault rupture spared the house from further damage.



Photo 4 (to FER-234). Several previously unmapped northeast-trending faults (Fault Zone A) occurred west of the Johnson Valley fault in the Flamingo Heights area. The house at locality 19 (Figure 3a) was damaged by a fault that had 10 cm of right-lateral and 10 cm of southeast side down vertical displacement.



Photo 5 (to FER-234). The ruptures at locality 19 (Figure 3a; Photo 4) are characterized by a complex pattern of extensional and right-oblique slip offset. View is to the northeast of a garage damaged by surface fault rupture.